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1    **The peak duration-specific locomotor demands and concurrent collision**  
2    **frequencies of European Super League rugby.**

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19

20    **Abstract**

21    Understanding the most demanding passages of European Super League  
22    competition can optimise training prescription. We established positional and match  
23    half differences in peak relative distances ( $\text{m}\cdot\text{min}^{-1}$ ) across durations, and the number  
24    of collisions, high-speed- and very-high-speed-distance completed in the peak 10 min  
25    period. Moving-averages (10 s, 30 s, 1 min, 5 min, 10 min) of instantaneous speed  
26    ( $\text{m}\cdot\text{s}^{-1}$ ) were calculated from 25 professional rugby league players during 25 matches  
27    via microtechnology. Maximal  $\text{m}\cdot\text{min}^{-1}$  was taken for each duration for each half.  
28    Concurrently, collisions (n), high-speed- (5 to 7  $\text{m}\cdot\text{s}^{-1}$ ; m) and very-high-speed-  
29    distance (> 7  $\text{m}\cdot\text{s}^{-1}$ ; m) were coded during each peak 10 min. Mixed-effects models  
30    determined differences between positions and halves. Aside from peak 10 s, *trivial*  
31    differences were observed in peak  $\text{m}\cdot\text{min}^{-1}$  between positions or halves across  
32    durations. During peak 10 min periods, adjustables, full- and outside-backs ran more  
33    at high-speed and very-high-speed whilst middle- and edge-forwards completed more  
34    collisions. Peak  $\text{m}\cdot\text{min}^{-1}$  is similar between positional groups across a range of  
35    durations and are maintained between halves of the match. Practitioners should  
36    consider that whilst the overall peak locomotor ‘intensity’ is similar, how they achieve  
37    this differs between positions with forwards also exposed to additional collision bouts.

38

## 39    **Introduction**

40    Rugby league is played professionally in the European Super League (ESL) and in  
41    Australasia within the National Rugby League (NRL). It is a team-sport characterised  
42    by prolonged intermittent bouts of locomotor and collision activity (Waldron, Twist,  
43    Highton, Worsfold & Daniels, 2011; Gabbett, Jenkins & Abernethy, 2012; Johnston,  
44    Gabbett & Jenkins, 2014; Twist et al., 2014). Practitioners prescribe numerous  
45    training modes to develop the wide range of physical qualities (e.g. muscular strength,  
46    speed) that are needed to succeed in competition (Gabbett et al., 2012; Till,  
47    Scantlebury & Jones, 2017; Weaving et al., 2017). However, in order to improve the  
48    likelihood of positive outcomes it is important to manage the accumulation and  
49    distribution of the external and internal loads prescribed to players (Impellizzeri,  
50    Rampinini & Marcora, 2005; Soligard et al., 2016; Vanrenterghem, Nedergaard,  
51    Robinson & Drust, 2017). By understanding the most intense periods of competition,  
52    practitioners can improve their prescription of the external load (i.e. running,  
53    accelerating, collisions) across training modes and ensure players are appropriately  
54    exposed to these demands in training (Impellizzeri et al., 2005; Weaving et al., 2017).

55    Microtechnology units incorporating global positioning systems (GPS) chips and other  
56    inertial measurement devices are now widely used to quantify both the locomotor  
57    (Johnston et al., 2014) and collision demands (Gabbett et al., 2012; Hulin, Gabbett,  
58    Johnston & Jenkins, 2017) of professional rugby league competition. Across a whole  
59    match, players typically cover between 5000 and 8000m (Waldron et al., 2011; Twist  
60    et al., 2014; Johnston et al., 2014) and are subjected to 30-65 collision events (Hulin  
61    et al., 2017) dependent on position (Gabbett et al., 2012). Whilst whole-game data  
62    are useful to understand the accumulation of load and how it varies by position,  
63    quantifying the rate in which this activity accumulates (i.e. 'intensity') is important for  
64    understanding the specificity of training.

65 Relative distance ( $\text{m}\cdot\text{min}^{-1}$ ) is a frequently reported measure used to quantify the  
66 overall rate of locomotor activity during competition (Waldron et al., 2011; Twist et al.,  
67 2014; Johnston et al., 2014). In a systematic review, Johnston et al. (2014) reported  
68 23 positional relative distances from 9 manuscripts across the NRL ( $n = 7$ ) and ESL  
69 ( $n = 2$ ) competitions. The mean data across these studies suggests the whole-game  
70 relative distance to be  $\sim 94.7 \pm 6.1 \text{ m}\cdot\text{min}^{-1}$ . However, the utility of this information as  
71 a basis to prepare players is questionable because it under-represents periods in the  
72 game where players complete greater relative distances for prolonged periods of time  
73 (i.e.  $> 5 \text{ min}$ ) (Delaney et al., 2015). Technical-tactical training is a commonly  
74 prescribed modality in professional rugby league training programmes (Gabbett et al.,  
75 2011; Lovell et al., 2013; Weaving et al., 2017). Therefore, identifying the maximal  
76 relative distances across a range of time periods should provide useful information  
77 for technical-tactical coaches to evaluate their training prescription (Robertson &  
78 Joyce, 2015).

79 Delaney et al. (2015) used a moving-average of the instantaneous sampled speed  
80 ( $5\text{Hz m}\cdot\text{s}^{-1}$ ) during NRL competition. Using this approach, the authors were able to  
81 determine the between-position differences in peak relative distances completed  
82 across 1 to 10 min moving average periods. Logically, as the duration of activity  
83 decreased, the peak relative distance for a given duration increased (Delaney et al.  
84 2015). Interestingly, however, substantial differences in total distance between player  
85 positions have been observed using whole-game data (Waldron et al., 2011; Twist et  
86 al., 2014; Johnston et al., 2014). Delaney et al. (2015) reported that full-backs  
87 completed substantially greater peak relative distances across the range of durations  
88 compared with players in other positions (i.e. halves, outside backs, edge-forwards  
89 and hit-up-forwards), who covered similar peak relative distances. For example, the  
90 mean maximal 10 min relative distance reported across a NRL season for full-backs  
91 was  $105 \pm 10 \text{ m}\cdot\text{min}^{-1}$ , with halves ( $93 \pm 10 \text{ m}\cdot\text{min}^{-1}$ ), middle forwards ( $90 \pm 10 \text{ m}\cdot\text{min}^{-1}$ )

92 <sup>1</sup>), edge forwards ( $95 \pm 7 \text{ m}\cdot\text{min}^{-1}$ ) and outside backs ( $97 \pm 14 \text{ m}\cdot\text{min}^{-1}$ ) covering  
93 substantially reduced relative distances. Due to the previously reported differences in  
94 whole-game relative distances (including high-speed) between the two competitions  
95 (Twist et al., 2014), this would seem important to establish in the ESL.

96 Given the interplay that occurs between locomotor and collision activity in rugby  
97 league, one limitation of the above study (Delaney et al., 2015) is that the collision  
98 activities completed by players during periods of peak locomotor intensity were not  
99 reported. Hit-up-forwards have less playing time (Johnston et al., 2014), despite  
100 Delaney et al. (2015) demonstrating little practical difference in the peak running  
101 demands for this position compared to positions which complete the full match.  
102 Increased collision activity (Gabbett et al., 2012) and body mass (Darrall-Jones et al.,  
103 2015; Jones et al., 2015) compared to other positions are possible mechanisms for  
104 this reduced involvement. However, whilst the frequency of collision activity of whole-  
105 match NRL competition has previously been detailed (Gabbett, Jenkins & Abernethy,  
106 2011; Gabbett et al., 2012; Cummins & Orr, 2015), concurrent data relating to collision  
107 activity embedded within the peak locomotor (i.e. relative distances) distances  
108 covered during ESL competition is currently unavailable. However, provision of such  
109 data would provide practitioners with extremely useful information with which to  
110 generate a holistic understanding of the most demanding passages of play for the  
111 positional groups. These data could then be used as collective markers of “intensity”  
112 to assist practitioners to plan the incremental progression of both collision and  
113 locomotor activity during physical preparation (i.e. pre-season) and return-to-play  
114 protocols.

115 Based on the information above, we designed the current study with the specific aim  
116 of: 1) establishing the positional differences in duration-specific peak relative  
117 distances covered during ESL competition; 2) establishing the positional differences  
118 in high-speed-distance ( $5 \text{ to } 7 \text{ m}\cdot\text{s}^{-1}$ ), very-high-speed-distances ( $> 7 \text{ m}\cdot\text{s}^{-1}$ ) and the

119 number of concurrent collisions within the peak 10 min relative distances of ESL  
120 rugby; and 3) establishing the within-position differences in these demands between  
121 halves of the match.

## 122 **Method**

### 123 **Participants**

124 Data were collected from 25 male professional rugby league players (age =  $27.3 \pm$   
125  $4.8$  yrs, body mass =  $96.0 \pm 12.6$  kg and height =  $184.5 \pm 6.8$  cm) from the same ESL  
126 club during 25 matches during the 2017 ESL regular season (18 wins, 7 losses; mean  
127  $\pm$  SD score margin:  $4 \pm 21$  points). Players were coded for position at the start of each  
128 match, with the number of match observations and individual player appearances for  
129 each position including: fullbacks (5 players;  $n = 25$ ), outside backs (centres and  
130 wings; 9 players;  $n = 96$ ), adjustables (half-back, five-eighth; hooker; 6 players;  $n =$   
131  $72$ ), middle-forwards (middle- and loose-forward; 10 players;  $n = 92$ ) and edge-  
132 forward (6 players;  $n = 48$ ). The mean  $\pm$  SD number of matches per player was  $16 \pm$   
133  $6$ . When a player changed position within a half their data was omitted from the  
134 dataset ( $n = 7$ ). Players provided informed consent and ethics approval was gained  
135 from the institutions review board.

136 Microtechnology (Optimeye S5, Catapult Innovations, Melbourne, Victoria) was  
137 positioned in a customised padded pouch sewn into the players shirt which was  
138 positioned in the centre of the upper back. To reduce the influence of inter-unit error,  
139 each player was provided with the same device for the period of data collection. The  
140 test-retest reliability of Catapult 10Hz devices to measure instantaneous speed  
141 across a range of starting velocities has been reported to be acceptable (coefficient  
142 of variation: 2.0 to 5.3%) (Varley et al., 2012). The number of satellites and horizontal  
143 dilution of precision (HDOP) during data collection were (mean  $\pm$  SD)  $15 \pm 2$  and  $0.8$

144  $\pm 0.6$ , respectively. Greater than 6 connected satellites and HDOP values less than 1  
145 are considered ideal for GPS data collection (Malone, Lovell, Varley & Coutts, 2016).

146 *Duration-specific peak relative distance ( $m \cdot min^{-1}$ )*

147 During matches, each players period of involvement in the game was coded in real-  
148 time using proprietary software (Catapult Openfield v1.14; firmware: 7.27) (Weaving,  
149 Whitehead, Till & Jones, 2017; Barrett, 2017). A Greenwich mean time (GMT) 'time-  
150 stamp' was created to determine the 'start' and 'end' time of each players involvement  
151 in each half. This was also completed for interchange players to ensure that only  
152 match time were included in the analysis and to ensure appropriate coding of their  
153 involvement. For inclusion in any match half, a players involvement had to be greater  
154 than 20 min. This criteria was applied so that even if a player had two involvements  
155 in a single half, only one data entry per half per player could be included in the final  
156 analysis (Delaney et al., 2015). All natural match breaks (e.g. injury, try  
157 scored/conceded) were included in the analysis.

158 To establish the duration-specific running intensities ( $m \cdot min^{-1}$ ), a players  
159 instantaneous speed ( $m \cdot s^{-1}$ ), derived from the Doppler Shift method, was recorded  
160 every 0.1s (i.e. 10Hz). A time-series file, detailing a record of instantaneous speed  
161 every 0.1s was then exported from the proprietary software (Catapult Openfield  
162 v1.14). Therefore, the first speed sample represents the 'start' of their match  
163 involvement (i.e., half or interchange period), whilst the final speed sample represents  
164 the 'end' of their involvement.

165 A custom-built algorithm using the zoo package (Zeileis & Grothendieck, 2005) in R  
166 (v R-3.1.3, R Foundation for Statistical Computing, Vienna, Austria) was developed  
167 to compute a moving-average of each player's instantaneous speed across different  
168 durations. Moving-averages were calculated across five different durations (10 s, 30  
169 s, 1 min, 5 min, 10 min) for each half. Like previous studies (Delaney et al., 2015),



170 these durations were arbitrarily chosen to represent shorter and prolonged durations  
171 of activity due to their use in training prescription. For example, for a 10 min moving-  
172 average, the algorithm computed a moving-average for every 6000 instantaneous  
173 speed samples (i.e. 10 samples per second for 600 seconds [10 min]). This process  
174 was repeated for each of the respective 'durations' in the study. For each player and  
175 half, the respective computed moving-average values for each duration were then  
176 concatenated into a data frame (with the columns representing the different moving  
177 average durations [i.e. 10 s to 10 min] and the rows representing the moving average  
178 instantaneous speed value). This was then exported to Microsoft Excel to determine  
179 the maximum moving-average for each duration. This was multiplied by the moving-  
180 average duration to determine a players maximal moving-average of relative distance  
181 ( $\text{m}\cdot\text{min}^{-1}$ ).

182 *Concurrent collision-, high-speed- and very-high-speed-distance within peak 10 min*  
183 *relative distances*

184 The number of collisions, high-speed-distance ( $5$  to  $7 \text{ m}\cdot\text{s}^{-1}$ ) and very-high-speed-  
185 distance ( $>7 \text{ m}\cdot\text{s}^{-1}$ ) were selected to provide additional information of the concurrent  
186 locomotor and collisions with the peak 10 min relative distances ( $\text{m}\cdot\text{min}^{-1}$ ) identified  
187 during ESL competition (Twist et al., 2014; McLellan, Lovell & Gass, 2011). The  
188 minimum effort duration for high-speed and very-high-speed distance was set at 1  
189 second (Varley, Jaspers, Helsen & Malone, 2017; Malone et al., 2017).

190 PlayerLoad™ was quantified as per previous methods which has demonstrated  
191 acceptable reliability (Boyd, Ball & Aughey, 2011). The number of collisions were  
192 quantified using the 'tackle' algorithm provided by the manufacturer which is derived  
193 from the 100Hz tri-axial accelerometer and gyroscope also housed within the  
194 microtechnology device as per previous methods. This has been reported to possess  
195 acceptable validity to detect collision events, with specificity and sensitivity of  $91.7 \pm$

2.5% and  $93.9 \pm 2.4\%$  respectively, when short duration ( $< 1$  second) and low-intensity (i.e.  $< 1$  AU of PlayerLoad™) events were excluded (Hulin et al. 2017).

To export the number of collisions, high-speed- and very-high-speed-distance completed by each player, the GMT associated with the identified peak  $10 \text{ m}\cdot\text{min}^{-1}$  moving-average for each half match file were coded within the proprietary software (Openfield v1.14, Catapult Innovations, Scoresby, Victoria, Australia) and exported into a customised spreadsheet.

### 203 **Statistical Analysis**

Linear mixed-effects models were used to estimate the differences between the positional groups and match half. For the continuous variables of 10 s, 30 s, 1-min, 5 min and 10 min peak  $\text{m}\cdot\text{min}^{-1}$ , 10 min high-speed-distance and very-high-speed-distance, estimations were made via PROC MIXED in SAS University Edition (SAS Institute, Cary, NC). For collision data, a generalised linear mixed-effects model was used, assuming a negative binomial distribution, via the *lme4* package (Bates, Maechler, Bolker & Walker 2015) in R (version 3.3.1). In both models the (fixed) effects of playing position and match-half were estimated. The interaction between these fixed effects was also explored, by including a multiplicative term in the models. The random effects in both models were match identity (differences between average match demands not accounted for by the fixed effects), athlete identity (differences between athletes' mean match demands) and the residual (within-athlete match-to-match variability). Magnitude-based inferences were used to provide an interpretation of the real-world relevance of the outcomes. For all peak relative distance durations, a difference of  $10 \text{ m}\cdot\text{min}^{-1}$  was set as the smallest worthwhile effect threshold. This was chosen based on previous research (Delaney et al., 2015) as practitioners are unlikely to utilise between-position training prescription that is more specific than a 10 metre difference. For collisions, high-speed- and very-high-speed-distance comparisons, a value equivalent to a difference in means of 0.20 was set as the

223 smallest worthwhile effect threshold. For all comparisons, effects were classified as  
224 *unclear* if the percentage likelihood that the true effect crossed both positive and  
225 negative smallest worthwhile effect thresholds were both greater than 5%. Otherwise,  
226 the effect was deemed clear, and was qualified with a probabilistic term using the  
227 following scale: <0.5%, *most unlikely*; 0.5-5%, *very unlikely*; 5-25%, *unlikely*; 25-75%,  
228 *possible*; 75-95%, *likely*; 95-99.5%, *very likely*; >99.5%, *almost certainly* (Hopkins,  
229 2009).

## 230 **Results**

### 231 *Duration-specific peak relative distance ( $m \cdot min^{-1}$ )*

232 Table 1 details the mean  $\pm$  SD for peak relative distances from 10 s to 10 min by 1<sup>st</sup>  
233 and 2<sup>nd</sup> half. Between halves of the match (1<sup>st</sup> vs 2<sup>nd</sup>) there were *likely* to *most likely*  
234 trivial differences in these variables for all within-position comparisons.

235 Table 2 details the raw least square means positional differences and magnitude  
236 based inferences for these variables. Although, full backs, outside backs and  
237 adjustables covered substantially greater relative distances across 10 s periods, there  
238 were *possibly* to *almost certainly* trivial differences between all positional groups in  
239 peak 1, 5 and 10 min relative distances.

### 240 *Concurrent collisions, high-speed- and very-high-speed-distances within peak 10 min* 241 *relative distances ( $m \cdot min^{-1}$ )*

242 Table 1 displays the mean  $\pm$  SD for peak 10 min relative distance and concurrent  
243 number of collisions, high-speed- and very-high-speed-distance for each positional  
244 group.

245 Figure 1, 2 and 3 displays the standardised mean difference plus 90% confidence  
246 intervals for positional differences in the concurrent number of collisions, high-speed-  
247 and very-high-speed-distance completed during the peak 10 min relative distances.

248 Whilst there were *unclear* differences in the number of collisions between full backs,  
249 adjustables and outside backs, edge and middle forwards completed a substantially  
250 greater number of collisions compared to these three positional groups.

251 Between 1<sup>st</sup> and 2<sup>nd</sup> halves there were *possibly* reductions in high-speed distance for  
252 full-backs (ES: 0.25 [-0.20 to 0.69]), *very likely* reductions for outside backs (ES: 0.54  
253 [0.32 to 0.76]), *possibly* trivial reductions for adjustables (ES: 0.13 [-0.12 to 0.38]),  
254 *possibly* reductions for middle forwards (ES: 0.29 [0.06 to 0.51]) and *likely* reductions  
255 for edge forwards (ES: 0.40 [0.09 to 0.71]). For very-high-speed-distance, there were  
256 *likely* reductions between 1<sup>st</sup> and 2<sup>nd</sup> halves for full backs (ES: 0.44 [-0.03 to 0.92])  
257 and outside backs (ES: 0.40 [0.16 to 0.64]) and *possibly* trivial differences for  
258 adjustables (ES: -0.10 [-0.36 to 0.17]) and middle forwards (ES: 0.12 [-0.13 to 0.36]).  
259 *Unclear* differences were observed for wide-forwards (ES: -0.04 [-0.37 to 0.29]). For  
260 collisions, there were *likely* trivial differences between 1<sup>st</sup> and 2<sup>nd</sup> halves for all  
261 positional groups.

## 262 **Discussion**

263 The primary aim of the study was to establish the positional differences in peak  
264 duration-specific relative distances and the number of collisions, high-speed-, and  
265 very-high-speed-distances completed within the peak 10 min locomotor period of ESL  
266 competition. A secondary aim was to determine whether these peak demands differed  
267 between the 1<sup>st</sup> half and 2<sup>nd</sup> half of competition within positional groups.

268 The main findings were that whilst adjustables, outside- and full-backs completed  
269 greater peak running 'intensities' during 10 s locomotor bouts, *likely to almost certainly*  
270 trivial differences were observed between all the positional groups as the duration  
271 increased (30 s to 10 min). Although, during the peak 10 min locomotor period,  
272 adjustables outside- and full-backs covered greater high-speed and very-high-speed-  
273 distances than middle- and edge-forwards, the latter positional groups completing a

274 substantially greater number of collisions. The difference in demands between 1<sup>st</sup> and  
275 2<sup>nd</sup> halves were *likely* to *almost certainly* trivial across the majority of variables,  
276 although there were small decreases in high-speed- and very-high-speed-distance  
277 across all positional groups during the peak 10 min locomotor period of the 2<sup>nd</sup> half.  
278 Collectively this suggests for prolonged periods of an ESL match (i.e. 2 x 10 min  
279 periods), the positions demonstrate limited practical differences in overall relative  
280 distance, although middle- and edge-forwards complete a greater number of  
281 collisions, whereas fullbacks, outside backs and adjustables complete greater  
282 distances at high-speed during this time. This study is the first to provide data of the  
283 peak locomotor and concurrent collision activity of ESL rugby by halves of the match.  
284 The findings suggest that it is important for coaches to prescribe periods of training  
285 that provide positional groups with similar exposures to relative distance, while still  
286 ensuring that the respective positions achieve this in a different manner (i.e. backs  
287 more high-speed running) and that they are concurrently exposed to varying collision  
288 activity (i.e. forwards more collisions).

289 Compared to previous literature (Delaney et al., 2015), the peak duration-specific  
290 relative distances of ESL competition appear comparable to those reported within the  
291 NRL. This suggests that the peak locomotor demands of the two competitions are  
292 consistent. Consequently, there appears to be a growing body of evidence to suggest  
293 that the peak duration-specific relative distances of professional rugby league  
294 competition are consistent across teams and competitions and therefore, when  
295 controlling for contextual influences, there appears to be a 'ceiling' requirement of  
296 relative distance that professional rugby league players are required to complete.  
297 Importantly, it must be considered that the data in the current study represents the  
298 average of the maximal relative distances covered by players per half, per game.  
299 Therefore, detailing the range of peak demands experienced by players, including the  
300 maximal recorded exposure during competition can also provide useful information of

301 the highest recorded demands (Table 1). For example, whilst whole-game relative  
302 distances are  $\sim 94.7 \text{ m}\cdot\text{min}^{-1}$  (Johnston et al., 2014), at least 10% of the match (i.e. 2  
303 x 5 min) is spent covering relative distances between 107 and  $116 \text{ m}\cdot\text{min}^{-1}$ . Depending  
304 on position, this rose to between 134 to  $165 \text{ m}\cdot\text{min}^{-1}$  during some matches (Table 1).  
305 Practitioners should therefore aim to ensure players receive an appropriate exposure  
306 to technical-tactical activities at these maximal competition 'intensities'.

307 Due to the importance of 'winning' the collision contest and its interplay with locomotor  
308 activity, a novel aspect of the current investigation was the detail and positional  
309 comparison of the frequency of collision bouts during the peak 10 min locomotor  
310 periods of ESL competition. These appear similar to the whole-game collision  
311 frequencies ( $\text{number}\cdot\text{min}^{-1}$ ) reported in the NRL (Gabbett et al., 2012) which revealed  
312 middle-forwards (mean [range]:  $1.09 [0.96 \text{ to } 1.22]$ ) to exhibit the greatest frequency  
313 of collisions, with differences also observed between wide-running-forwards ( $0.76$   
314  $[0.69 \text{ to } 0.84]$ ), adjustables ( $0.58 [0.45 \text{ to } 0.71]$ ) and outside backs ( $0.38 [0.32 \text{ to } 0.43]$ ). This suggests that during the peak locomotor passages of ESL competition,  
316 the frequency of collision activity is maintained at whole-game 'intensities'. Therefore,  
317 practitioners should consider the amalgamation of collision activity whilst aiming to  
318 replicate the 'peak' relative distances reported in the current study. However, it is  
319 important to note that the current study quantified the collisions embedded within the  
320 peak locomotor demands and it is plausible that the peak frequency of collisions for  
321 a given duration could be substantially greater than those reported. Future research  
322 should therefore seek to establish the peak collision frequencies experienced by the  
323 positional groups for a range of durations to further strengthen the understanding  
324 between locomotor and collision activity during professional rugby league  
325 competition.

326 In professional rugby league it is commonplace for forwards (particularly middle-  
327 forwards) to complete reduced time on the pitch during matches (Waldron et al., 2011;

Twist et al., 2014; Johnston et al., 2014). This has previously been attributed to forwards possessing reduced prolonged intermittent running capacity (Scott et al., 2017), greater body mass (Jones et al., 2015; Darrall-Jones et al., 2016) and greater collision activity compared to backs (Gabbett et al., 2012). Our study suggests that this is likely because middle-forwards complete similar peak locomotor intensities to backs whilst concurrently completing substantially more collisions for prolonged periods of the match (i.e. 2 x 10 min). When locomotor bouts are controlled, the addition of collisions have been reported to increase a players rating of perceived exertion, blood lactate concentration and heart rate (Johnston & Gabbett, 2011; Mullen, Highton & Twist, 2015; Norris, Highton, Hughes & Twist, 2016), suggesting that the internal physiological cost of competition would be greater in the forwards position. In addition, the total number of contacts in the forwards position has previously been reported to relate to decrements in perceptual muscle soreness ( $r = 0.62$ ), perceptual fatigue ( $r = 0.69$ ) and countermovement jump flight time ( $r = -0.55$ ) 24 hours post ESL competition (Twist, Waldron, Highton, Burt & Daniels, 2012). Despite this, such substantial relationships appear to be absent in the backs (soreness:  $r = 0.20$ ; fatigue:  $r = 0.11$ ; jump flight time:  $r = -0.25$ ) (Twist et al., 2012). Collectively, this suggests that rugby league forwards are subjected to greater psycho-physiological and biomechanical loads (Soligard et al., 2016; Vanrenterghem et al., 2017) per min of competition than backs, leading to similar amounts of “fatigue” in the days following competition, despite forwards competing for a reduced amount of time (Twist et al., 2012; Johnston et al., 2014). Therefore, practitioners should ensure that training prescription and recovery periodisation reflect this, particularly when forwards complete substantially greater playing times than typically accustomed to.

Whilst this study is the first to detail the interplay between locomotor and collision activity during the peak passages of competition and how they differ between position

355 and halves of the match, the study is not without limitations. Firstly, the data were  
356 collected from a single ESL club, which may not be representative of the differences  
357 observed with other teams in the competition. Secondly, the collision, high-speed-  
358 and very-high-speed-distance demands embedded within the peak 10 min duration  
359 were extracted on the assumption that the measurement of instantaneous speed  
360 ( $\text{m}\cdot\text{s}^{-1}$ ) provides a valid representation of the peak locomotor demands of professional  
361 rugby league competition (Delaney et al., 2015). Acceleration and deceleration events  
362 are prevalent in professional rugby league, due to the spatial constraints imposed by  
363 the 10-metre rule separating the opposing structures of the attacking and defending  
364 teams. Therefore, determining the collisions, high-speed- and very-high-speed  
365 distances completed within the peak acceleration demands could arguably provide a  
366 more valid representation of the peak locomotor demands of competition.

367 Despite this, for the practitioner wishing to optimise training prescription, it is important  
368 to find the balance between the validity of the measurement and practical/actionable  
369 data. In particular, during the planning and prescription of training a fundamental  
370 strategy adopted by practitioners is to control and manipulate the overall distance  
371 covered per unit of time (i.e. relative distance). This warrants consideration, as  
372 technical-tactical training is the most frequently prescribed modality in professional  
373 rugby league, particularly during the in-season period which lasts the majority of the  
374 calendar year (Gabbett et al., 2012; Lovell et al., 2013; Weaving et al., 2017).  
375 Therefore, it would be preferable to appropriately expose players to these peak  
376 demands (e.g. 10 min continuous bouts) within this mode of training to concurrently  
377 satisfy both the physical and technical-tactical requirements of training. Achieving this  
378 would allow practitioners to prescribe an appropriate range of training stimuli whilst  
379 also ensuring players are contained within an appropriate overall accumulation of  
380 training load (Gabbett, 2016). Furthermore, instantaneous speed can also be  
381 monitored in real-time (Barrett et al., 2017; Weaving et al., 2017). This is unlike



382 acceleration data, which can only be monitored post-session. Consequently,  
383 acceleration variables can be difficult for the practitioner to translate into the  
384 actionable manipulation of training content. Regardless, previous work has reported  
385 the peak duration-specific acceleration and relative distance demands to occur at  
386 different periods within a match (Delaney et al., 2016). This highlights that the  
387 retrospective analysis of acceleration demands during specific training drills is  
388 warranted. In particular, within a specific duration of rugby league activity, it is likely  
389 that the interplay between the magnitude of instantaneous speed and acceleration  
390 plus collision activity would provide the best representation of the 'most demanding'  
391 durations of professional rugby league competition.

392 It is therefore recommended that further research be undertaken in order to better  
393 understand the interaction between these three components coupled with their own  
394 individual peak demands (which may occur at different times to each other) during  
395 the peak passages of competition. Ideally, future research should look to the link the  
396 peak interactions between these three modes of activity and the associated technical-  
397 tactical/skill activities that are completed within such periods.

## 398 **Conclusions**

399 Aside from very-short-duration bouts (i.e. 10 s), there are trivial differences in the peak  
400 relative distances covered between positions during ESL competition. However,  
401 adjustables, outside- and full-backs cover substantially greater high-speed- and very-  
402 high-speed-distances during the peak 10 min relative distance period than middle-  
403 and edge-forwards whilst the forwards positional groups complete a greater number  
404 of collisions. There are likely trivial differences between these demands between  
405 halves of competition, suggesting that players are likely to be exposed to similar peak  
406 intensities for each given period in both halves of the match.

## 407 **Practical Applications**

- 408 • To simulate the peak running intensities of ESL competition, practitioners  
409 should expose positional groups to similar peak relative distances and  
410 durations during training.
- 411 • Given the similarities between match halves across durations, programming  
412 multiple peak bouts within a training session could help to prepare players for  
413 competition.
- 414 • How positions achieve this overall relative distance should differ, with  
415 adjustables, outside- and full-backs completing greater high-speed- and very-  
416 high-speed-distances.
- 417 • During the peak 10 min running 'intensity' of ESL, forwards complete a greater  
418 frequency of collisions and should be exposed to these demands whilst  
419 completing similar relative distances.

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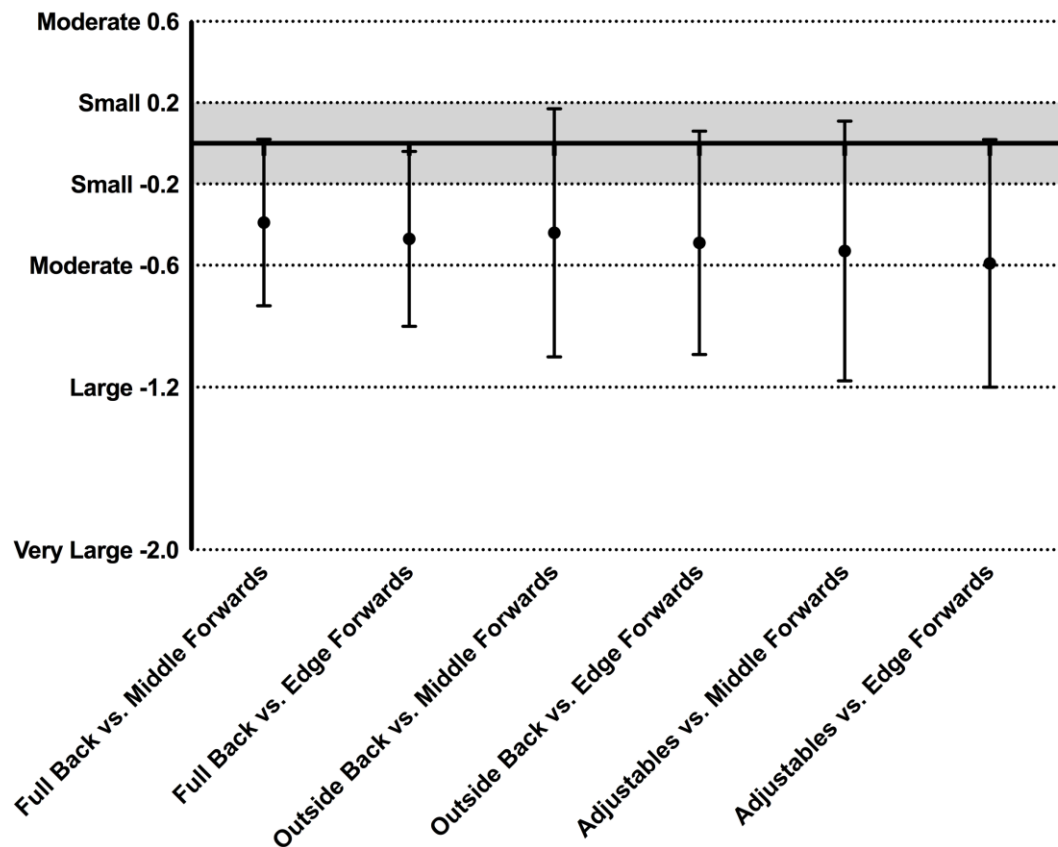
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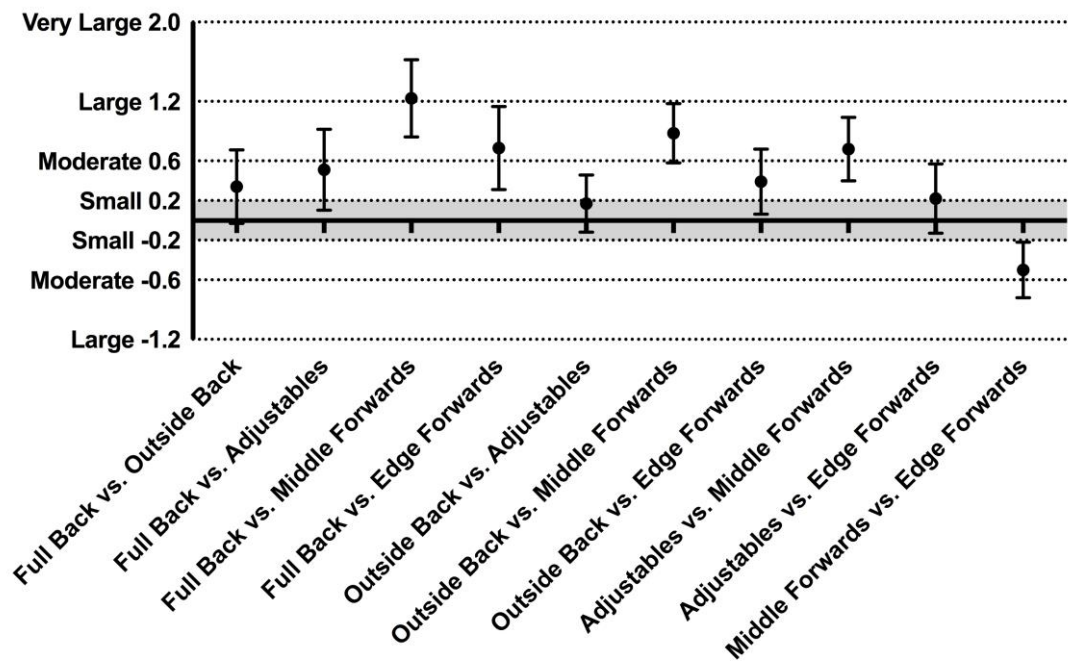
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**Figure 1. The standardised mean positional differences plus 90% confidence intervals for the number of collisions completed during the peak 10 min of European Super League rugby. Only substantial differences are detailed. Outside backs vs. fullbacks (-0.07 [-0.47 to 0.34]), adjustables vs. fullbacks (-0.15 [-0.61 to 0.32]), outside backs vs. adjustables (0.09 [-14.59 to 14.76]) and middle forwards vs. edge forwards (-0.06 [-3.76 to 3.64]) were all *unclear*.**





555 **Figure 2. Standardised mean positional differences plus 90% confidence**  
556 **intervals in high-speed-distance (5 to 7 m·s<sup>-1</sup>) completed during the peak 10**  
557 **min of European Super League rugby.**

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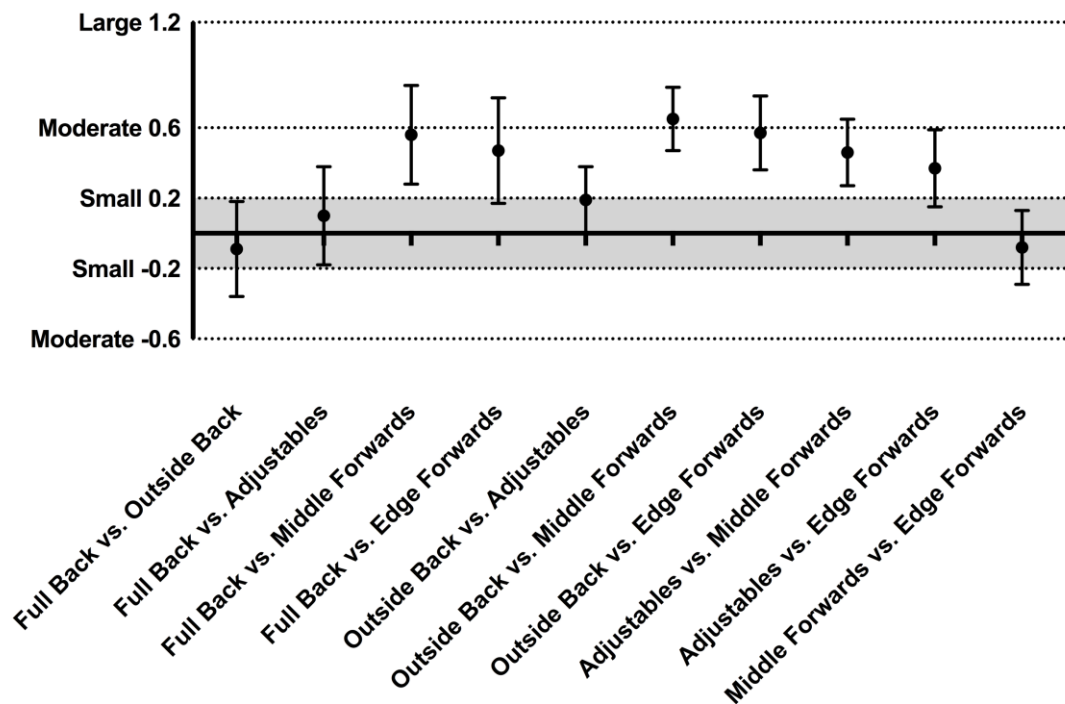
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570 **Figure 3. Standardised mean differences plus 90% confidence intervals for the**  
 571 **positional differences in very-high-speed-distance ( $> 7 \text{ m}\cdot\text{s}^{-1}$ ) completed**  
 572 **during the peak 10 min of European Super League rugby.**

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**Table 1. The mean  $\pm$  standard deviation of duration-specific peak 1<sup>st</sup> and 2<sup>nd</sup> half relative distances of European Super League rugby and the concurrent number of collisions, and high-speed- and very-high-speed-distances covered during the peak 10-minute relative distances.**

	10s (m·min <sup>-1</sup> )	30s (m·min <sup>-1</sup> )	1-min (m·min <sup>-1</sup> )	5-min (m·min <sup>-1</sup> )	10-min (m·min <sup>-1</sup> )	10-min HSD (m)	10-min VHSD (m)	Collisions (n)
<b>Fullback</b>								
1 <sup>st</sup> Half	320.8 $\pm$ 10.6	209.7 $\pm$ 5.2	169.7 $\pm$ 3.8	118.7 $\pm$ 2.8	102.9 $\pm$ 2.3	89.2 $\pm$ 8.4	9.3 $\pm$ 2.1	5.2 $\pm$ 3.0
2 <sup>nd</sup> Half	331.4 $\pm$ 10.9	209.5 $\pm$ 5.3	167.7 $\pm$ 3.8	115.2 $\pm$ 2.8	101.6 $\pm$ 2.3	80.9 $\pm$ 8.6	4.8 $\pm$ 2.2	5.7 $\pm$ 3.6
<b>Outside back</b>								
1 <sup>st</sup> Half	325.2 $\pm$ 6.3	200.5 $\pm$ 3.3	169.7 $\pm$ 3.8	110.9 $\pm$ 1.9	96.1 $\pm$ 1.8	82.6 $\pm$ 5.2	10.1 $\pm$ 1.1	5.1 $\pm$ 2.6
2 <sup>nd</sup> Half	325.2 $\pm$ 6.3	203.1 $\pm$ 3.3	167.7 $\pm$ 3.8	106.4 $\pm$ 1.9	92.3 $\pm$ 1.8	64.5 $\pm$ 5.2	5.9 $\pm$ 1.1	4.9 $\pm$ 2.5
<b>Adjustable</b>								
1 <sup>st</sup> Half	313.0 $\pm$ 7.1	200.3 $\pm$ 3.7	160.7 $\pm$ 2.4	113.8 $\pm$ 2.1	99.9 $\pm$ 2.0	70.1 $\pm$ 5.9	5.5 $\pm$ 1.3	5.5 $\pm$ 3.3
2 <sup>nd</sup> Half	322.5 $\pm$ 6.9	205.8 $\pm$ 3.6	159.5 $\pm$ 2.4	111.6 $\pm$ 2.1	96.9 $\pm$ 1.9	65.7 $\pm$ 5.8	6.5 $\pm$ 1.2	5.2 $\pm$ 3.2
<b>Middle forward</b>								
1 <sup>st</sup> Half	291.5 $\pm$ 6.2	195.5 $\pm$ 3.2	163.1 $\pm$ 2.4	111.1 $\pm$ 1.9	99.0 $\pm$ 1.8	48.7 $\pm$ 5.1	1.9 $\pm$ 1.1	9.7 $\pm$ 2.6
2 <sup>nd</sup> Half	281.7 $\pm$ 6.3	195.8 $\pm$ 3.2	160.8 $\pm$ 2.4	106.0 $\pm$ 1.9	94.2 $\pm$ 1.8	39.2 $\pm$ 5.1	0.7 $\pm$ 1.2	9.1 $\pm$ 2.8
<b>Edge forward</b>								
1 <sup>st</sup> Half	296.2 $\pm$ 7.9	191.8 $\pm$ 3.9	159.9 $\pm$ 2.9	110.0 $\pm$ 2.2	99.3 $\pm$ 2.0	60.6 $\pm$ 5.4	2.0 $\pm$ 1.5	8.9 $\pm$ 2.7
2 <sup>nd</sup> Half	298.3 $\pm$ 7.7	197.8 $\pm$ 3.8	160.4 $\pm$ 2.8	105.9 $\pm$ 2.1	95.1 $\pm$ 1.9	53.9 $\pm$ 6.1	2.4 $\pm$ 1.5	8.2 $\pm$ 2.7

HSD = high-speed-distance (5-7 m·s<sup>-1</sup>); VHSD = very-high-speed-distance (>7 m·s<sup>-1</sup>)

**Table 2. Raw mean positional differences [90% confidence limits] and likelihoods in peak relative distances across durations**

	<b>10s</b> <b>(m·min<sup>-1</sup>)</b>	<b>30s</b> <b>(m·min<sup>-1</sup>)</b>	<b>1 min</b> <b>(m·min<sup>-1</sup>)</b>	<b>5 min</b> <b>(m·min<sup>-1</sup>)</b>	<b>10 min</b> <b>(m·min<sup>-1</sup>)</b>
<b>FB vs. OB</b>	0.96 [-14.2 to 16.1] <i>Unclear</i>	7.8 [0.4 to 15.2] <i>Possibly trivial</i>	8.6 [3.2 to 14.1] <i>Possibly trivial</i>	8.3 [4.4 to 12.1] <i>Likely trivial</i>	8.0 [5.2 to 10.9] <i>Likely trivial</i>
<b>FB vs. ADJ</b>	8.38 [-7.7 to 24.4] <i>Unclear</i>	6.5 [-1.5 to 14.6] <i>Likely trivial</i>	5.3 [-0.7 to 11.3] <i>Likely trivial</i>	4.2 [-0.1 to 8.5] <i>Very likely trivial</i>	3.8 [0.5 to 7.1] <i>Almost certainly trivial</i>
<b>FB vs. MF</b>	39.6 [24.2 to 55.0] <i>Almost Certainly ↑</i>	14.0 [6.3 to 21.7] <i>Likely ↑</i>	6.7 [1.0 to 12.5] <i>Likely trivial</i>	8.4 [4.3 to 12.6] <i>Possibly trivial</i>	5.7 [2.3 to 9.1] <i>Very likely trivial</i>
<b>FB vs. EF</b>	28.9 [12.3 to 45.4] <i>Very likely ↑</i>	14.8 [6.6 to 23.0] <i>Likely ↑</i>	8.5 [2.4 to 14.7] <i>Possibly trivial</i>	9.0 [4.6 to 13.4] <i>Possibly trivial</i>	5.0 [1.4 to 8.6] <i>Very likely trivial</i>
<b>OB vs. ADJ</b>	7.4 [-3.8 to 18.6] <i>Possibly Trivial</i>	-1.3 [-7.0 to 4.4] <i>Very likely trivial</i>	-3.3 [-7.6 to 1.0] <i>Almost certainly trivial</i>	-4.0 [-7.1 to -1.0] <i>Almost certainly trivial</i>	-4.2 [-6.6 to 1.8] <i>Almost certainly trivial</i>
<b>OB vs. MF</b>	38.6 [27.8 to 49.4] <i>Almost Certainly ↑</i>	6.2 [0.5 to 11.8] <i>Likely trivial</i>	-1.9 [-6.2 to 2.5] <i>Almost certainly trivial</i>	0.1 [-3.1 to 3.4] <i>Almost certainly trivial</i>	-2.4 [-5.3 to 0.6] <i>Almost certainly trivial</i>
<b>OB vs. EF</b>	27.9 [15.6 to 40.2] <i>Very likely ↑</i>	7.0 [0.7 to 13.3] <i>Likely trivial</i>	-0.1 [-4.9 to 4.7] <i>Almost certainly trivial</i>	0.7 [-2.8 to 4.2] <i>Almost certainly trivial</i>	-3.0 [-6.1 to 0.1] <i>Almost certainly trivial</i>
<b>ADJ vs. MF</b>	31.2 [19.6 to 42.8] <i>Almost certainly ↑</i>	7.4 [1.4 to 13.5] <i>Likely trivial</i>	1.4 [-3.2 to 6.1] <i>Almost certainly trivial</i>	4.2 [0.71 to 7.6] <i>Almost certainly trivial</i>	1.83 [-1.3 to 5.0] <i>Almost certainly trivial</i>
<b>ADJ vs. EF</b>	20.5 [7.5 to 33.5] <i>Likely ↑</i>	8.3 [1.6 to 15.0] <i>Possibly trivial</i>	3.2 [-1.9 to 8.3] <i>Very likely trivial</i>	4.7 [1.0 to 8.5] <i>Very likely trivial</i>	1.17 [-2.2 to 4.5] <i>Almost certainly trivial</i>

579	<b>MF vs. EF</b>	-10.7 [-22.0 to 0.7]	0.9 [-4.7 to 6.4]	1.8 [-2.3 to 5.9]	0.6 [-2.3 to 3.5]	-0.7 [-2.8 to 1.47]
580		<i>Possibly ↓</i>	<i>Almost certainly</i> <i>trivial</i>	<i>Almost certainly</i> <i>trivial</i>	<i>Almost certainly</i> <i>trivial</i>	<i>Almost certainly</i> <i>trivial</i>
581	FB = fullback; OB = outside back; ADJ = adjustables; MF = middle forward; EF = edge forward. The direction of					
582	difference is in relation to the first named positional group.					
583						